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EFFECT OF EARTHQUAKE LOAD ON UNREINFORCED BLOCK MASONRY WALLS

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Abstract: *Unreinforced Masonry structures are susceptible to damage in earthquakes. It is therefore very important to enhance the seismic capacity of block masonry buildings. Masonry is an effective alternative technique to improve performance against and resistance to ground excitations. This research primarily focuses on the comparative study of the unreinforced block masonry. One block masonry walls i.e. unreinforced were tested in order to compare their strength, ductility and effective stiffness after the application of reverse cyclic loading. The values of displacement ductility (μ_D), Response modification factor (R) and displacement amplification factor (C_d) were calculated. The three performance levels namely Collapse Prevention (C.P), Life safety (L.S) and immediate occupancy (I.O) were calculated with the help of ASCE standards to judge their performance level. It was observed that the Block Masonry Wall performed superiorly in all the ASCE performance level conditions the Unreinforced Block Masonry wall. The performance increased by 18% in I.O performance level, 2 7% in L.S level and by 25% in C.P level in case of Unreinforced Block Masonry wall.*

Keywords: *Unreinforced Block Masonry, Performance levels, Kashmir Earthquake*

1. Introduction:

After 2005 Kashmir earthquake it is of paramount importance to study and explore the building resistivity to overcome the lateral forces which are generated during earthquakes. Pakistan lies in one of the most dynamic seismic zones all over the world with the fault line passing through Northern Areas which significantly increases the probability of great loss of building and life.

A survey conducted by the Civil Engineering Department, University of Engineering and Technology, Peshawar, concluded that unreinforced construction constitutes a major about three fourths of the construction in the earthquake prone regions of the country increasing the seismic risk, Shahzada, 2012. The unreinforced masonry buildings were either partially or completely damaged as reported by the reconnaissance survey. The main causes of failure elaborated in the report were poor quality of construction and workmanship, and weak interlocking between in-plane and out of plane walls. To avoid such large scale disaster in the future such technique needs to be explored which increases the overall strength of the building structure, stiffness and ductility.

In the past few decades a lot of work has been carried out in the area of Confined block masonry and its seismic performance. Zeeshan et al. (2015) has carried out full scale seismic testing of the unreinforced concrete block masonry indicating the various areas of crack propagation. Similarly, Zeeshan et al. (2015) has worked on the retrofitting techniques of the unreinforced block masonry. Brzev, S. (2007) has specified the various key factors influencing the seismic resistance in the confined masonry. Moorani et al. (2004) has pointed out a superior performance of the masonry against the 1935 earthquake (Surface Wave Magnitude 8.3) that hit the Chile. However, little research has been carried out in the field of Block Masonry, being a common practice of construction in the Northern Regions of Pakistan.

In this context the research was designed to develop a comparative study of the unreinforced Block Masonry. Both the test specimens were subjected to the same Quasi - Static loading conditions in which they exposed to both vertical and horizontal loading conditions.

2. Investigational Procedure

The testing procedure was divided into three phases

1. Materials selection stage
2. Properties investigation stage
3. Main testing stage

2.1 Material Selection Stage

Block masonry units of nominal dimensions 12”x8”x6” (width x length x height) were utilized in the fabrication of test specimens of unreinforced. Cement used was obtained from Cherat Cement Factory. Sand of Lawrencepur was used to effectively simulate the actual field material usage in the laboratory. According to ASTM C270, Cementitious materials and aggregate were mixed for 3 to 5 minutes continuously with maximum amount of water to make workable consistency. Mixing was done with the help of paddle type mixer. Mortar was placed within 20 minutes before it started setting.

1.2 Material Properties

Summary of the material properties investigated with the different testing procedure are given in **Table 1.**

Table 1: Summary of the material properties

S.No	Description	Standard Testing Procedure Adopted	Symbols	Results
1	Co-efficient of Friction	EN-1052-3	μ	0.07
2	Masonry Compressive Strength	ASTM C-1314	$f_{m'}$	1800 psi
3	Compressive Strength of Mortar	ASTM C 109	$f_{m'o}$	733 psi
4	Modulus of Rupture,	ASTM C-140 & Popov and Balan (1998)	f_{bt}	479.2 psi
5	Initial Rate of Absorption	ASTM C-67	IRA	0.81 ${g/min}/{30in^2}$
6	Water Absorption of Blocks	C1403-15	W_{ab}	4.88%

2.3. Main Testing Stage

2.3.1 Test Specimens

One of unreinforced block masonry was constructed of blocks immersed in water prior to use.
Each wall had two piers and one opening. A concrete foundation 21ft x 21ft x 6in was provided. A 12in x 8in concrete beam was cast on each wall.
The unreinforced wall it was provided above the door only. The wall was cast monolithic with the top concrete beam (dimensions 8in x 6in) and foundation and openings were vertical reinforced concrete elements of dimensions 6in x 8in.
Unreinforced walls were fixed on the RCC slab in order to keep the bottom of both the specimen fixed and the top free to move.

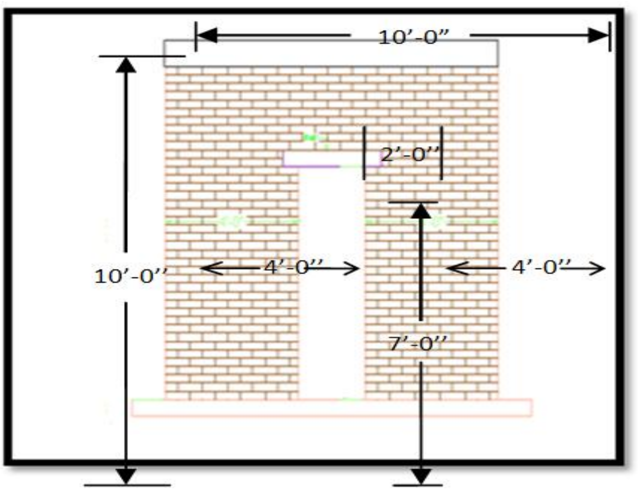

Figure 2: Unreinforced Block Masonry Wall

2.3.3 Experimental Test Setup

The test set up was arranged in such a way that only the bottom was fixed, whereas, free rotation and translation was permitted at the top. Loads were applied through hydraulic jacks. Horizontal and vertical loads were measured through load cells of capacities of 56 kip and 112 kip. A swivel was used to connect the jacks in both dimensions to the top of the concrete. This was done to release vertical and horizontal translation. The loading arrangement for the test setup is given in Figure 2.

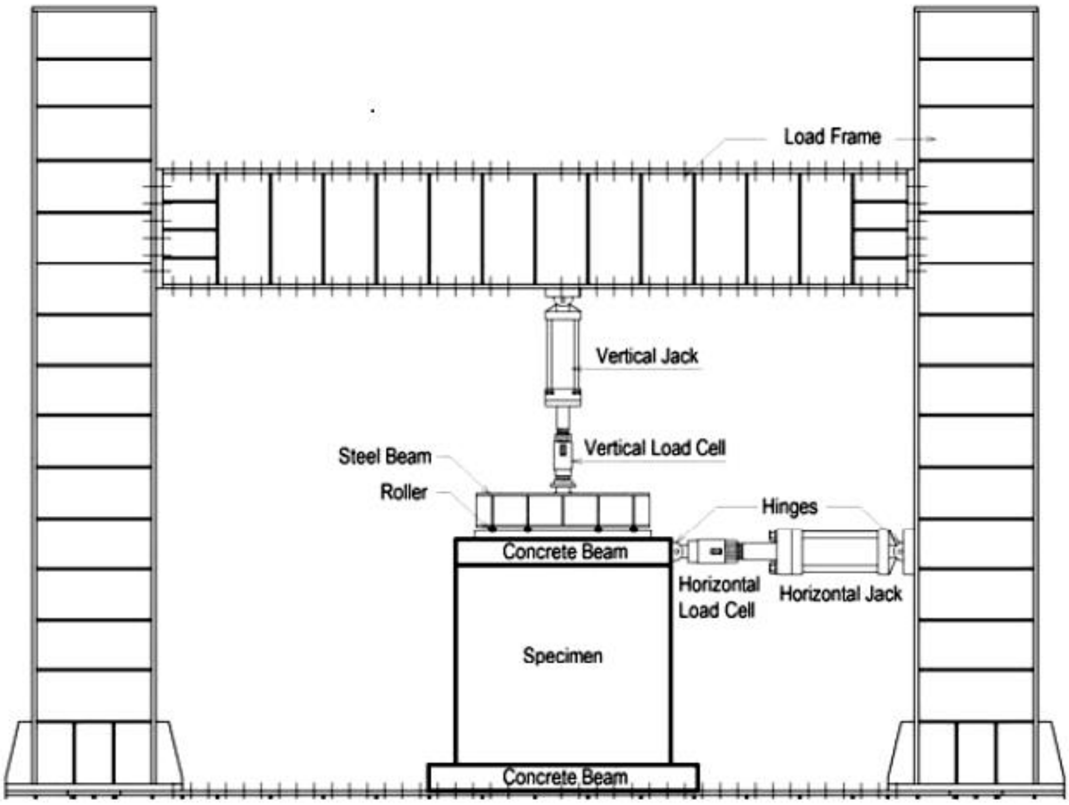

Figure 2: Quasi Static test setup

For recording the displacements 13 Linear Variable Displacement Transducers (LVDT) were used. Gauge 0 indicated the movement of the horizontal load cell. Gauge No.1 was used to record the in-plane displacement at the middle centre of the wall. Gauge 2 was fitted at the back side of the top beam and gauge 3 was fitted in front of the lintel beam. Gauge 4 and 5 were installed at the right and left side of the wall. Gauge 6 and 10 were fitted as diagonal gauges at the right pier of the wall to measure whereas the gauge 11 and 12 were fitted as diagonal gauges on the left pier of the wall. Gauge 13 and 14 were fitted as the vertical gauges on the left and right sides of the wall. Gauge 17 was fitted to control the vertical load cell.

2.3.6 Testing Procedure

The structures were tested in displacement controlled environment under a pre-compression of 20 tons each cycle starting from 0.02in. Control was taken as the horizontal displacement of the beam cast on top of the wall at the farther side of the wall. Damage to the structure was noted and marked throughout the testing procedure. The test was terminated after complete degradation of the in-plane strength.

The horizontal loading was applied in the following stages and each stage consists of 3 cycles. The loading rate was 0.25 mm, 0.5 mm, 0.75 mm and 1.00 mm in the first four cycles. The loading rate was then increased to 1.5 mm, 2.0 mm, 2.5 mm, 3.0 mm, 3.5 mm, and 4 mm. The incremental change in the loading rate in the later stages was 6.0 mm, 8.0 mm, 10.0 mm, 12.0 mm, 14.0 mm, 16.0 mm, and 18.0 mm. In case of the unreinforced specimen the loading rate was stopped at 18 whereas, for the specimen the loading was increased to 20.0 mm, 24.0 mm, and 27.0 mm based on the damage pattern of the walls.

4.0 Results

4.1 Failure Modes of the Block Masonry Walls

4.1.1 Failure Mode or Damage Pattern of Unreinforced Wall

Twenty tons pre-compression load was applied to the unreinforced masonry wall as a representation of the effects of double story building.

The first crack developed near the sill of the opening at 0.1% story drift (3mm displacement) at the lateral load of 7.25 tons.

In the second phase, the cracks created around the opening propagated diagonally from the sill to the spandrel and some horizontal cracks were observed at the bottom of the piers in the mortar joints at 0.2% story drift (6mm displacement) at the lateral load of 10.60 tons.

In third phase, the cracks were developed diagonally in the piers and propagated through the mortar joints at 0.26% story drift (8mm displacement) at the lateral load of 11.50 tons. These are the most common cracks developed in the pier failure. The crack propagation for the unreinforced block masonry is given in Figure 3. Figure 4 represent the actual pictures of the test specimen after failure at a story drift of 0.26 % (8 mm) at a lateral loading of 11.5 tons.

In the final phase, crushing of blocks occurred at the following location.

- Two blocks were crushed in the pier at 0.4% story drift (12mm displacement) under the lateral load of 12.70 tons.
- Blocks in the toe at 0.53% story drift (16mm displacement) under the lateral load of 13.4 tons were also crushed as show in Figure 5.

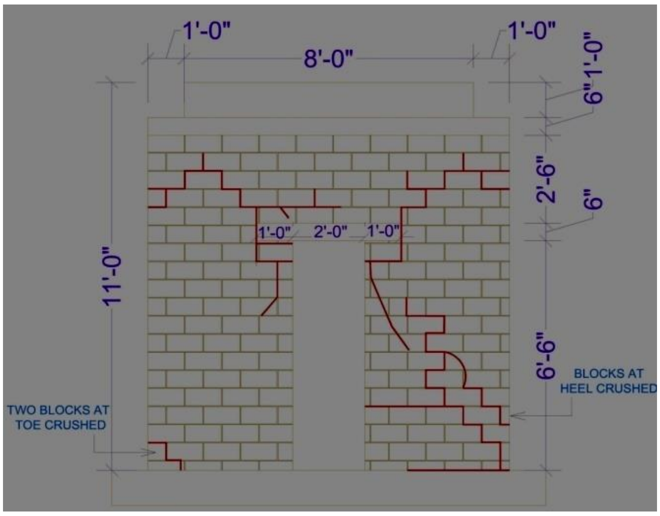

Figure 3: Crack Pattern for Unreinforced Block Masonry Wall at a Story Drift of 0.53 %(16mm)

Figure 4: Diagonal Cracks Propagation in the Piers at a Story Drift of 0.26 % (8 mm displacement)

Figure 5: Crushing of Toe in Unreinforced Masonry Wall at a Story Drift of 0.53% (16 mm displacement)

4.2 Hysteretic Behavior

The hysteresis curves were drawn to explain the force deformation behavior for the unreinforced block masonry wall which is given in Figure 6 and Figure 7 respectively.

For the sign convention, southward movement of the hydraulic jack was taken positive having positive displacement to the adjacent lateral load. Where as, Northward movement of the hydraulic jack was taken as negative having negative displacement corresponding to adjacent lateral load.

The envelope curves were produced by connecting the points related to positive and negative displacements in each cycle.

The stiffness of the Unreinforced Block Masonry Wall decreased with the increase in displacements and for a story drift of 0.20% and at 0.25% it was almost zero.

At a Story drift of 0.33% for unreinforced masonry wall and 0.58%, the structures reached to their peak resistance after which the decrease in strength started slowly.

The strength reduced to 5% of the maximum load at a story drift of 0.39%.When the structure had gained suffered excessive cracks, the test was stopped.

Unreinforced masonry wall showed shear failure while the behavior of the masonry wall was more on the flexure side by virtue of the vertical and horizontal elements.

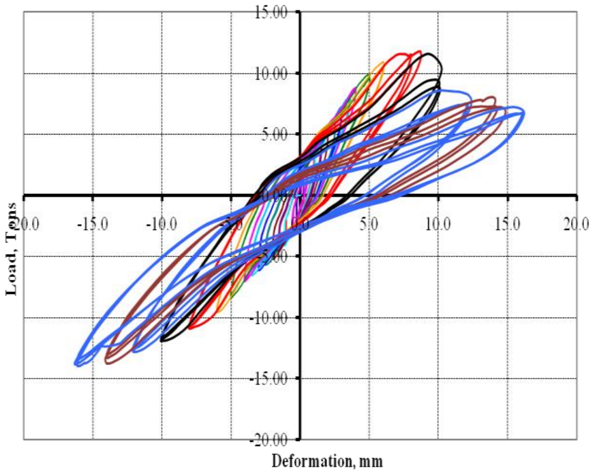

Figure 6: Hysteresis curve for Unreinforced Block Masonry Wall

4.3 Bilinear Idealization

With the help of equal energy principle, the average force deformation envelope curve was modified to Bilinear Curve. Magenes and Calvi (MC-97) were the first to generate the elasto-plastic curve. From the average Back bone curve following important terms were calculated.

- V_u was calculated by the expression $V_u = 0.9\ V_{max}$.
- The effective stiffness (K_{eff}) was taken as the ratio of $3*V_u / 4$ to the corresponding displacement in the envelope curve.
- Yield Displacement can be find out from $D_y=V_u/K_{eff}$
- Ultimate displacement was calculated by the point in the envelope curve corresponding to $4*V_u / 5$.
- The displacement ductility was calculated from
  $\mu_d = D_u/D_y$
- From Envelope curve of the unreinforced block masonry wall
  $\mu_d=2.73$
- R represent the Response Modification Factor which was calculated as

$$R = \sqrt{2\mu_D - 1}$$

- From Envelope curve of the unreinforced block masonry wall R = 2.11
- Displacement Amplification Factor was calculated from the expression

$$C_d = \mu_D \Big/ \sqrt{2\mu_D - 1}.$$

- For the Unreinforced block masonry wall $C_d=1.29$

Back bone curves were then developed from the hysteresis curves which are given in fig 7.

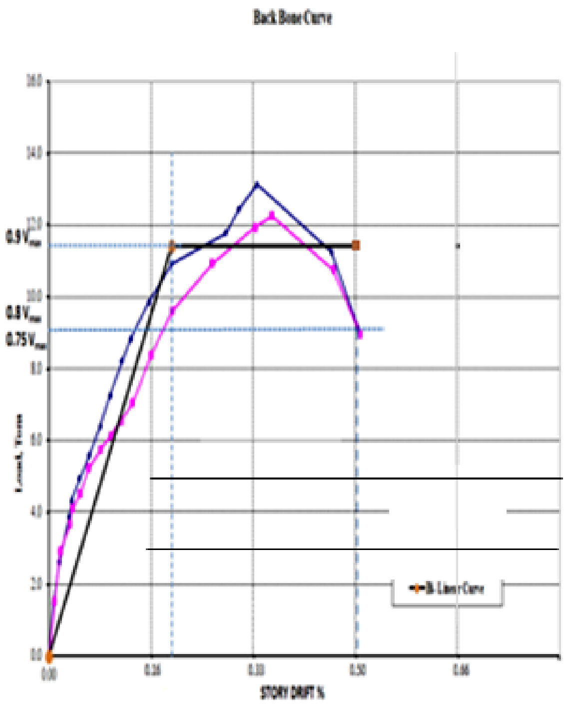

Figure 7: Back bone curve for Unreinforced Block Masonry Wall

4.4 Performance Levels of Unreinforced

ASCE describe three performance levels from the Average Bilinear Curves

- Immediate Occupancy (I.O)
  It is the point in the average bilinear curve which represents the drift corresponding to the yield point.
- Life Safety (L.S)
  It is the drift corresponding to 75% of C.P.
- Collapse Prevention (C.P)
  It is the point taken at which ultimate drift corresponding to lateral strength is dropped by 20%.
  From the back bone curves for the two walls the performance levels based on the (ACSE) criteria's were determined as shown in Figure 8 and Figure16.

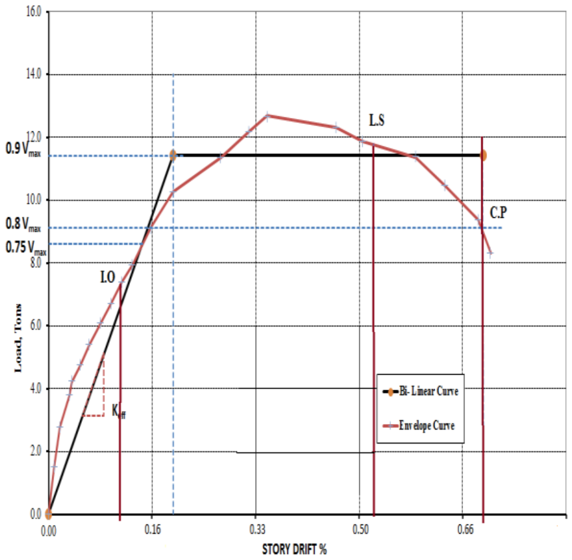

Figure 8: Unreinforced Masonry Wall Bilinear Curve

Table 3: Building Performance levels

Performance Level of Unreinforced Block Wall	Story Drift (%)
Intermediate Occupancy	0.11
Life Safety	0.52
Collapse Prevention	0.70

5. Conclusions

- Elements plays significant role in the increase of the lateral strength, ductility and effective stiffness of the block masonry.
- Crack propagation starts from the edge of the opening in the wall so it is very much important to provide vertical and horizontal elements to the opening to resist the crack propagations.
- The concrete blocks used as masonry unit in the Seismic prone areas are locally made without any proper mix design resulting in the poor quality of blocks. So it is important to use blocks from recommended plants only which execute the construction of blocks in the light of proper mix design.

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